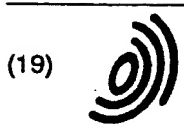


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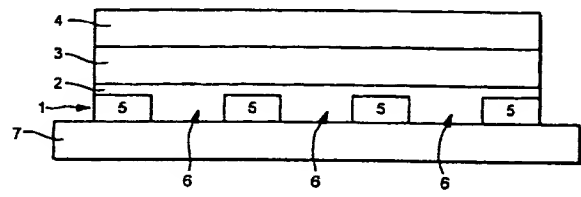
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(54) Electroluminescent device

(57) An electroluminescent device comprising: a first charge-carrier injecting layer for injecting positive charge carriers and a second charge-carrier injecting layer for injecting negative charge carriers, at least one of the charge-carrier injecting layers being patterned so as to comprise spaced-apart charge-injecting regions; an organic light-emitting layer located between the first and second charge-carrier injecting layers; and an unpatterned conductive polymer layer located between the organic light-emitting layer and the patterned charge-carrier injecting layer, the resistivity of the conductive polymer layer being sufficiently low to allow charge carriers to flow through it from the charge-injecting regions to generate light in the organic light-emitting layer but sufficiently high to resist lateral spreading of charge carriers beyond the charge-injecting regions.

FIG. 1



1, 2, 5, 8, 11, 12, 16, 17

EP 0 901 176 A2

## Description

[0001] This invention relates to electroluminescent devices, especially ones that have a conjugated polymer as a light-emitting layer.

[0002] One type of electroluminescent device is described in PCT/WO90/13148, the contents of which are incorporated herein by reference. The basic structure of this device is a light-emitting polymer film (for instance a film of a poly(p-phenylenevinylene) - "PPV") sandwiched between two electrodes, one of which injects electrons and the other of which injects holes. It is believed that the electrons and holes excite the polymer film, emitting photons. These devices are useful as flat panel displays, in which case one of the electrodes is transparent - for example being made of indium-tin oxide ("ITO").

[0003] One refinement of the device is that to allow the device to display information one of the electrodes can be patterned so that it only injects charge carriers over part of its area. The electrode can be patterned into discrete areas which can be controlled independently and each inject charge carriers into a respective discrete pixel of the polymer film.

[0004] Another refinement is that it has been found that the turn-on voltage, the brightness of the device at low voltage, the efficiency, the lifetime and the stability of the device can sometimes be improved by adding a layer of conductive polymer between the light-emitting film and one of the electrodes. In order to achieve these benefits these conductive polymer layers typically have a sheet resistance less than  $10^6$  Ohms/square (i.e. a sheet resistance less than  $10^6$  Ohms/square), the conductivity being controllable by doping of the polymer layer. One example of a suitable conductive polymer is polystyrene sulphonic acid doped polyethylene dioxythiophene ("PEDT-PSS") - see EP 0,686,662. For reasons which are discussed in more detail below, it is, however, difficult to produce good devices with an intermediate conductive polymer layer.

[0005] There have been some devices which could be regarded as a hybrid of these refinements. For instance, US 5,399,936 discloses a device in which the patterned electrode is covered by a hole-transporting/injecting organic layer of diphenyl-N-N'-bis(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine ("TPD"). However, the TPD is a small molecule, not a polymer, and it is undoped. WO 96/08047 discloses a device in which a conductive polymer layer is patterned to provide insulative regions and conductive regions to pixellate the display.

[0006] According to the present invention there is provided an electroluminescent device comprising: a first charge-carrier injecting layer for injecting positive charge carriers and a second charge-carrier injecting layer for injecting negative charge carriers, at least one of the charge-carrier injecting layers being patterned so as to comprise spaced-apart charge-injecting regions; an organic light-emitting layer located between the first

and second charge-carrier injecting layers; and an unpatterned conductive polymer layer located between the organic light-emitting layer and the patterned charge-carrier injecting layer, the resistivity of the conductive polymer layer being sufficiently low to allow charge carriers to flow through it from the charge-injecting regions to generate light in the organic light-emitting layer but sufficiently high to resist lateral spreading of charge carriers beyond the charge-injecting regions.

[0007] The patterned charge injecting layer could be an anode or a cathode. The other charge injecting layer (of opposite polarity) may be patterned or unpatterned. The width of the charge injecting regions is suitably less than 1mm, 300 $\mu$ m or 100 $\mu$ m, preferably less than 50 $\mu$ m and most preferably less than or around 20 $\mu$ m. The spacing between the charge injecting regions is suitably less than 1mm, 300 $\mu$ m or 100 $\mu$ m, preferably less than 50 $\mu$ m and most preferably less than or around 20 $\mu$ m.

[0008] The cathode is preferably a sputtered cathode. The cathode is preferably a low work function cathode. The cathode may be patterned by dry etching.

[0009] The light-emitting layer preferably is or comprises a semiconductive conjugated polymer such as PPV. The light-emitting layer suitably is or comprises PPV, poly(2-methoxy-5(2'-ethyl)hexyloxyphenylenevinylene) ("MEH-PPV"), a PPV-derivative (e.g. a dialkoxy derivative), a polyfluorene and/or a co-polymer incorporating polyfluorene segments, PPVs and/or related co-polymers. It could be deposited by spin-coating, dip-coating, blade-coating, meniscus-coating, self-assembly etc. The constituent of the light-emitting layer and/or its precursor is suitably water-based: examples are precursor-based PPVs. The thickness of the light-emitting layer is preferably in the range from 20 to 200nm and most preferably around 100nm.

[0010] The term "conjugated" indicates a polymer for which the main chain is either fully conjugated, possessing extended pi molecular orbitals along the length of the chain, or is substantially conjugated, but with interruptions to conjugation at various positions, either random or regular, along the main chain. It includes within its scope homopolymers and copolymers.

[0011] The conductive polymer layer preferably is or comprises polyethylene dioxythiophene ("PEDT"), polystyrene sulphonic acid doped polyethylene dioxythiophene ("PEDT-PSS"), doped polyaniline, a doped alkylthiophene and/or a doped polypyrrole. The thickness of the layer is suitably less than 200nm, preferably less than 100nm and most preferably less than or around 50nm. The sheet resistance of the layer is suitably greater than  $10^6$  or  $10^7$  Ohms/square, preferably greater than  $10^8$  Ohms/square and most preferably greater than or around  $10^{10}$  Ohms/square.

[0012] The conductivity of the conductive polymer layer is preferably adjustable (e.g. by means of additive components) over a relatively wide range. The conductive polymer is preferably doped with one or more components that influences its conductivity (e.g. polystyrene

sulphonic acid ("PSS") or epoxy-silane). The conductive polymer is suitable polyaniline, polypyrrole or a poly-thiophene.

[0013] The conductive polymer is preferably adapted to reduce its solubility and/or its interaction with an adjacent layer, especially a polymer layer. This layer is preferably the subsequent layer and most preferably the light emitting layer. To achieve this the conductive polymer preferably contains an additional component. This component is suitably a cross-linking agent (e.g. epoxysilane). This component preferably does not significantly impair the performance of the device, especially by increasing the drive voltage significantly, reducing the emission uniformity significantly or reducing the efficiency significantly. This component is especially advantageous in a device in which the conductive polymer and the light-emitting layer have the same or similar solvents. The amount of this component in the conductive polymer layer is suitably greater than 50wt%, preferably between 50wt% and 200wt% and most preferably around 100wt%.

[0014] Where the conductive polymer is PEDT-PSS the dilution of the PEDT-PSS with the PSS is preferably greater than 20% and most preferably greater than 50%. Any of these proportions may be used together with any of the proportions of epoxy-silane disclosed above.

[0015] The resistance of the conductive polymer layer is suitably such as to require an increase in the drive voltage of the device (compared to when the layer is absent) of 0.5V or less (preferably 0.2V or less) for equivalent device performance.

[0016] The present invention will now be described by way of example with reference to the accompanying drawings, in which:

figure 1 shows a cross-section of an electroluminescent device; and

figure 2 shows the chemical formula of PEDT-PSS.

[0017] Figure 1 shows an electroluminescent device having an anode layer 1 for injecting positive charge carriers, a conductive polymer layer 2, an organic light-emitting layer 3 and a cathode layer 4 for injecting negative charge carriers. The anode is patterned so as to comprise charge-injecting regions 5 (defining pixels) which are spaced from each other by gaps 6. The conductivity of the conductive polymer layer is selected so as to be low enough to allow for normal operation of the device (for instance, not so high that the drive voltage is increased significantly or that the efficiency or uniformity drops significantly) but high enough to resist cross-talk and lateral current-spreading between the charge-injecting regions and to resist off-pixel emission (so that the pixel edges are sharp and well-defined and there is no fuzzy emission edge to the pixels).

[0018] In more detail, the anode 1 is a layer of indium-tin oxide ("ITO") having a thickness of approximately

150nm. The widths of the pixel regions 5 and the gaps 6 are around 50µm.

[0019] The conductive polymer layer is a layer of PEDT-PSS with a thickness of around 50nm and a conductivity of around  $10^8$  Ohms/square. The layer also contains around 100wt% epoxy-silane to produce cross-linking.

[0020] The light-emitting layer 3 is a layer of PPV having a thickness of 100nm.

[0021] The cathode 4 is a layer of aluminium, having a thickness of 150nm.

[0022] The relatively high resistance of the conductive polymer layer resists cross-talk between the charge-injecting regions 5, with lateral off-pixel emission being restricted to within 10 or 5% of the pixel dimension and/or leakage of current outside the pixel boundary being restricted to 5 or 10% of the total current through the addressed pixel. And surprisingly, it has been found that even at conductivities of the conductive polymer layer as low as  $10^{10}$  Ohms/square the performance of the device is not necessarily impaired, the increase in drive voltage required being minimal.

[0023] A rough guide to the conductivity of the polymer layer that is required can be estimated with the aid of the following relationships:

for isotropic homogeneous conductivity media, the voltage drop across a device is given by:

$$V_d = j \perp R_{\square} t^2$$

$j$  = current/area

$t$  = thickness in units of area<sup>-1</sup>

$R_{\square}$  = sheet resistivity in  $\Omega/\square$

whereas the current between the ITO lines is:

$$j_{\perp} = (V/A) / R_{\square}$$

$A$  = aspect ratio of space between ITO lines

[0024] Clearly, the minimum advisable thickness of the polymer layer is dependant on the reliability of the process used to deposit the layer - if the layer is uneven and too thin in places then the anode and the light-emitting layer could make contact.

[0025] To produce the device, first the anode is deposited (on a glass substrate 7 for example) and patterned, e.g. by laser scribing, to define the charge-injecting and non-charge injecting regions. The charge injecting regions are connected individually to a control circuit so that they can be controlled independently and can thereby define pixel regions of the display, with each pixel region forming a column extending up from the corresponding charge injecting region.

[0026] A PEDT-PSS solution having a ratio of PEDT to PSS of 1:1.6 and a solid content of 1.2 to 1.3% is diluted further with extra PSS to achieve a PEDT to PSS ratio of 1:55 and a solid content of about 1%. Around 100wt%

FIG. 1

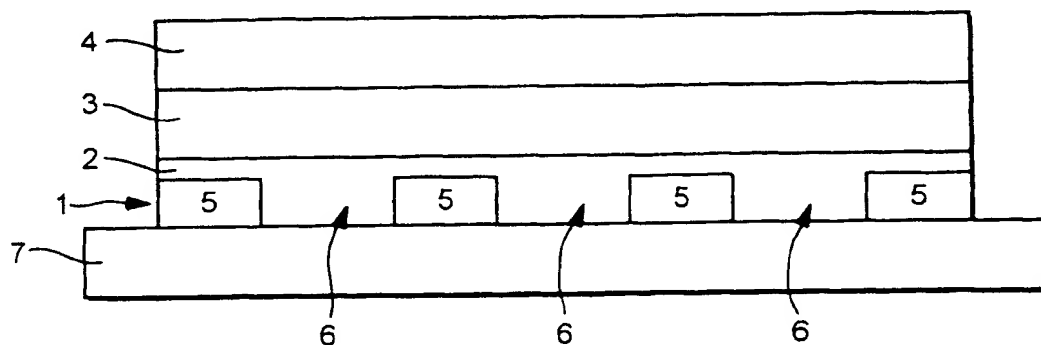
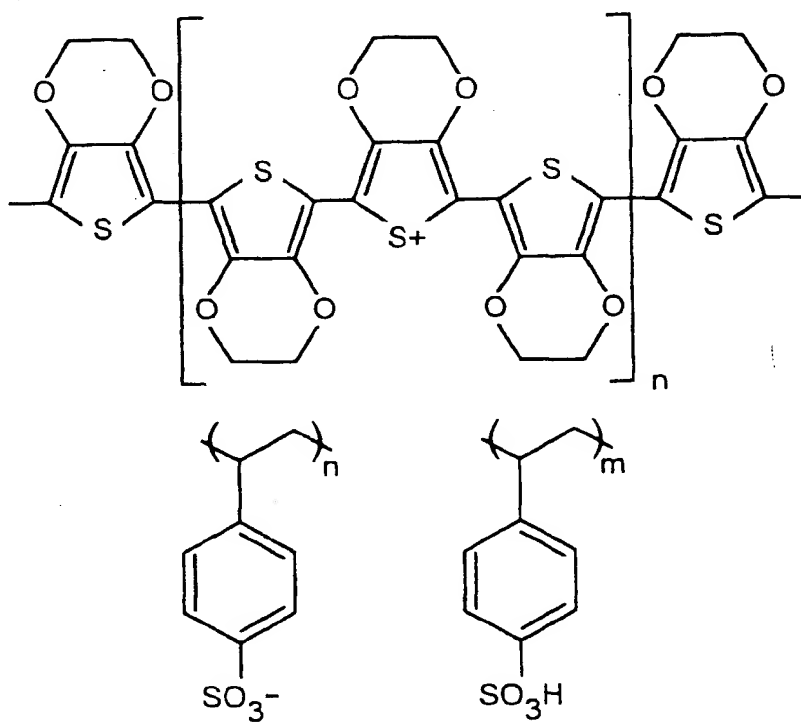


FIG. 2



- wherein the light-emitting layer comprises a semi-conductive conjugated polymer.
4. An electroluminescent device as claimed in any preceding claim, wherein the conductive polymer layer comprises polyaniline, polypyrrole or a polythiophene. 5
  5. An electroluminescent device as claimed in any preceding claim, wherein the conductive polymer layer comprises polyethylene dioxythiophene. 10
  6. An electroluminescent device as claimed in any preceding claim, wherein the conductive polymer layer comprises a dopant, the presence of which affects the resistivity of the conductive polymer layer. 15
  7. An electroluminescent device as claimed in claim 6, wherein the dopant is polystyrene sulphonic acid. 20
  8. An electroluminescent device as claimed in claim 6 or 7, wherein the conductive polymer layer contains greater than 50% dopant. 25
  9. An electroluminescent device as claimed in any preceding claim, wherein the conductive polymer layer comprises a component which reduces the solubility of the layer. 30
  10. An electroluminescent device as claimed in claim 8, wherein the component is epoxy-silane. 35
  11. An electroluminescent device as claimed in claim 9 or 10, wherein the conductive polymer layer contains greater than 50wt% of the component. 40
  12. An electroluminescent device as claimed in any preceding claim, wherein the sheet resistance of the conductive polymer layer is greater than  $10^6$  Ohms/square. 45
  13. An electroluminescent device as claimed in any preceding claim, wherein the regions of the light emitting layer capable of emitting light in use do not extend laterally beyond the charge injecting regions by more than 10% of the width of the charge injecting regions. 50
  14. An electroluminescent device as claimed in any preceding claim, wherein each charge-injecting region defines one or more pixel regions of the device. 55
  15. An electroluminescent device as claimed in any preceding claim, wherein each charge-injecting region is independent of the or each other charge-injecting region.
  16. An electroluminescent device as claimed in any preceding claim, wherein the first charge-carrier injecting layer is the patterned charge-carrier injecting layer.

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